

Aug. 1, 1961

W. E. MOTT
BOREHOLE LOGGING

2,994,774

Filed April 26, 1956

2 Sheets-Sheet 1

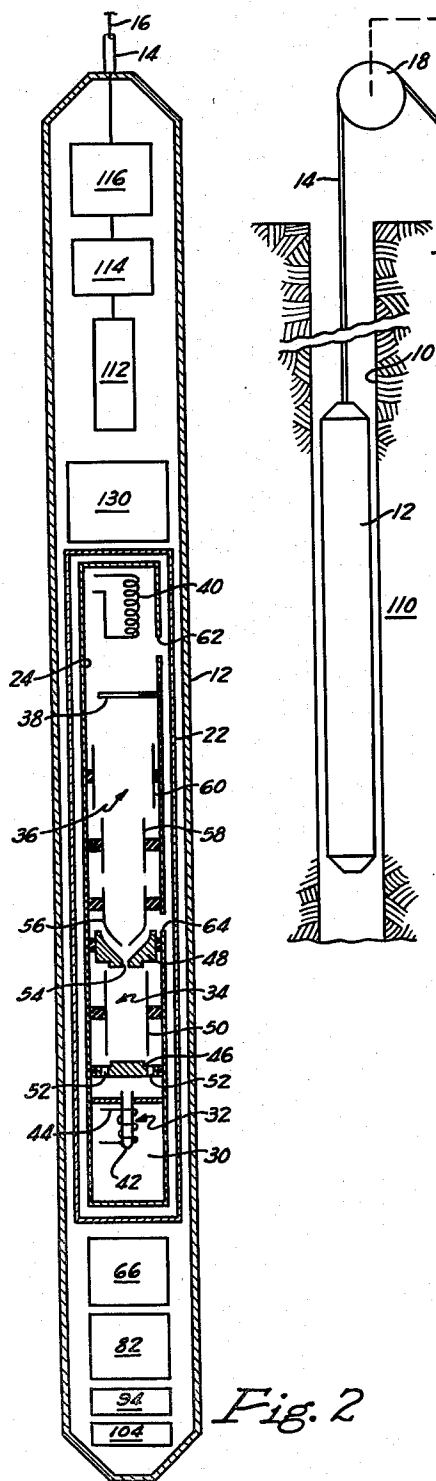


Fig. 2

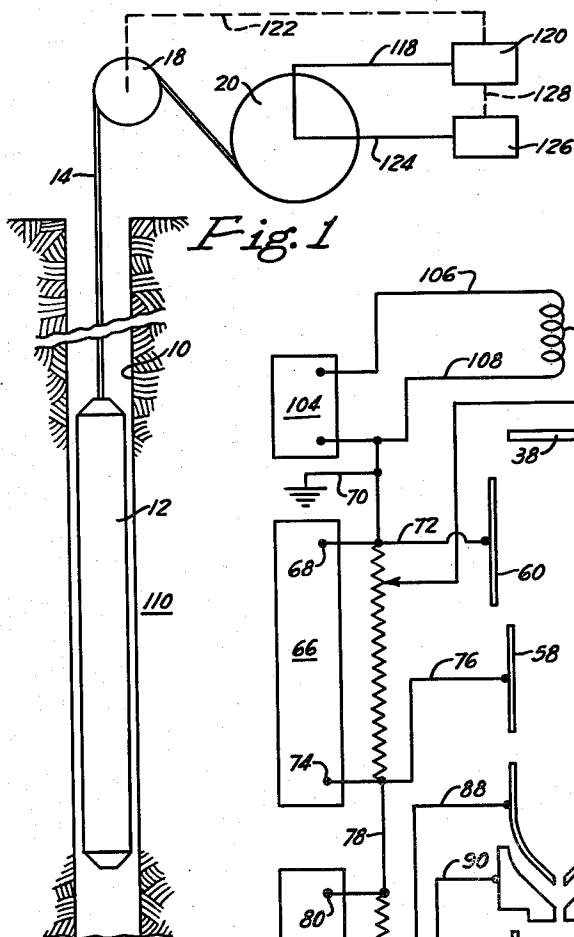


Fig. 1

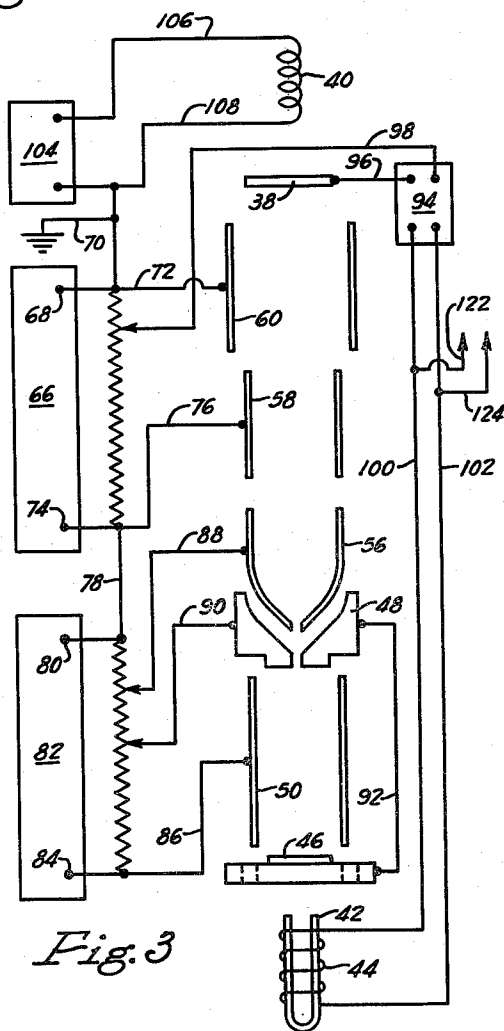


Fig. 3

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2 Sheets-Sheet 2

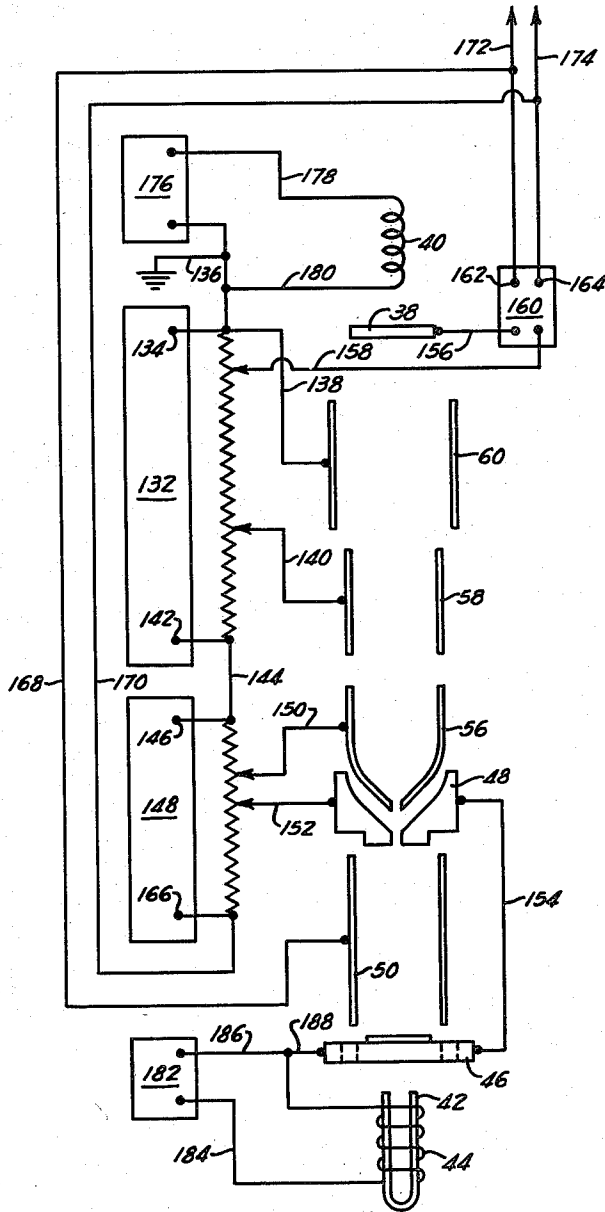


Fig. 4

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2,994,774

BOREHOLE LOGGING

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6 Claims. (Cl. 250-84)

This invention relates to new and useful improvements in apparatus and method for logging boreholes, and pertains more particularly to improving the constancy of a radiation source of the type wherein ions are accelerated to strike a target containing nuclei that undergo a nuclear reaction with the accelerated ions to produce the desired radiation. More specifically, this invention involves regulating the rate at which ions are produced to bombard the target so as to maintain the ion or target current constituted of ions striking the target substantially constant.

The instant invention is related to the same general class of subject matter as that disclosed in two other similarly assigned applications of mine filed concurrently with this application, one of such other applications being Serial No. 580,834, filed April 26, 1956, entitled "Logging Apparatus" and the other of such applications being Serial No. 580,906, filed April 26, 1956, entitled "Stabilized Borehole Logging."

Broadly, the present invention has to do with controlling either the rate at which material to be ionized is supplied to an ion source or the voltage applied to such ion source in a manner dependent upon the magnitude of the current constituted of ions striking the target (such current being hereinafter referred to as the ion or target current) so as to maintain the magnitude of such current substantially constant. Maintenance of the magnitude of such ion current substantially constant improves in large measure the constancy of the radiation output of the target.

The control of the rate at which material to be ionized is introduced into the ion source is such that the rate of introduction varies as an inverse function of the magnitude of the ion current. Inasmuch as an increase of pressure within the ion source within the normal range of operating pressures of the ion source increases the magnitude of the ion current, varying the rate at which material to be ionized is introduced into the ion source in the manner aforesaid tends to increase the magnitude of the ion current when the magnitude thereof has fallen below a predetermined value, and, conversely, tends to decrease the magnitude of such ion current when the magnitude thereof has increased above said predetermined value.

The control of the electrical potential applied to the ion source is such that the electrical potential varies as an inverse function of the magnitude of the ion current. Inasmuch as the magnitude of the ion current tends to increase with increased potential applied to the ion source, varying the electrical potential applied to the ion source in the manner aforesaid, tends to increase the magnitude of the ion current when such magnitude falls below a predetermined value, and, conversely, tends to decrease the magnitude of such ion current when the latter has increased to a value in excess of said predetermined value.

The principles of the invention are applicable to the production of either gamma rays or neutrons, and the term "penetrating radiation" is used in this specification and in the accompanying claims to define either or a combination of both gamma rays and neutrons. Irrespective of the nature of the penetrating radiation, the invention also encompasses the use of a radiation detector in

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conjunction with the source of penetrating radiation, and such radiation detector can be sensitive to either gamma rays or neutrons or any range or ranges of energies of gamma rays or neutrons.

The invention also entails recording detected radiation versus borehole depth and in addition optionally includes recording the magnitude of the ion or target current versus depth.

The invention will be better understood in the light of the following detailed description of preferred embodiments of the invention taken together with the accompanying drawings illustrative thereof, wherein:

FIGURE 1 is a diagrammatic representation of the apparatus shown in operative relation within a borehole;

FIGURE 2 is a schematic representation of the interior of the logging probe shown in FIGURE 1;

FIGURE 3 is a schematic electrical diagram illustrative of the electrical circuitry associated with some of the elements shown in FIGURE 2; and

FIGURE 4 is another embodiment of electrical circuitry that can be used in lieu of that shown in FIGURE 3.

Referring to the drawings, FIGURE 1 in particular, the numeral 10 designates a borehole in which a housing 12 is suspended for vertical movement upon the lower end of a cable 14. The cable 14 incorporates electrical conduit means 16 for purposes presently to become apparent, and is entrained over a supporting pulley 18 and wound upon a reel 20. The reel 20 is provided with conventional means, not shown, for driving and braking the same so that the housing 12 can be raised and lowered within the borehole 10.

Referring now to FIGURE 2, it will be seen that disposed within the housing 12 is a casing 22. The casing 22 is vacuum tight, and it as well as the housing 12 is formed of materials substantially transparent to penetrating radiation that is produced within the casing 22 by means presently to be described. A suitable material for the housing 12 is steel for the reasons that steel is reasonably transparent to penetrating radiation and possesses sufficient structural strength to withstand the hydrostatic pressures to which the housing 12 is subjected. The casing 22 can conveniently be formed of either steel or aluminum, as such materials possess sufficient structural strength to sustain a vacuum within the casing 22, as well as being substantially transparent to penetrating radiation.

Resiliently mounted, by means not shown, within the casing 22 is a hollow cylindrical container 24 that can be made of glass and which is closed at its upper and lower ends, as shown. Disposed within the container 24, as described in detail in my previously mentioned copending application entitled "Logging Apparatus," is a reservoir 30 for material to be ionized, valve means indicated generally at 32 for regulating the rate of introduction of material to be ionized into an ion source indicated generally at 34 that supplies ions to an accelerator indicated generally at 36, a target 38, an an ionic pump 40.

The valve means 32 can be any electrically-controllable type of valve means suitable for regulating minute gaseous flow rates; however, the illustrated preferred form of valve means 32 comprises a palladium thimble 42 and an electrical heating element 44 therefor. The palladium thimble 42 is generically referred to in the claims as a diffusion barrier so as to encompass equivalents thereof known to the art employing such substances as palladium and tantalum that possess the property of permitting an appreciable diffusion of hydrogen and its isotopes there-through at a rate that increases with increasing temperatures.

The ion source 34 comprises cathodes 46 and 48, and an anode 50. The cathode 46 is provided with openings

such as those shown at 52 for permitting the gas which passes through the valve means 32 to enter the ion source 34. The cathode 48 is provided with a small central opening 54 to constitute a restricted exit for ions to pass from the ion source 34 to the accelerator 36. Also, the cathodes 46 and 48 can be, and preferably are, made of or include magnetized material so that a strong magnetic field passes through the anode 50 between the cathodes 46 and 48.

The accelerator 36 comprises a probe electrode 56 and accelerating electrodes 58 and 60. The function of the accelerator 36 is to accelerate ions supplied by the ion source 34 to strike the target 38, preferably in a diffused manner.

The target 38 includes atomic nuclei that undergo a nuclear reaction with accelerated ions bombarding the target 38 to produce the penetrating radiation. Numerous variations are possible as to the selection of the type of accelerated ion and the type of atomic nuclei included in the target to produce one or the other or both types of penetrating radiation, or even to produce penetrating radiation of a particular energy level. Ordinarily, the accelerated ions will be either protons, deuterons or tritons, and that is the reason the particular illustrated form of valve means is employed. As will be apparent to those skilled in the art, the valve means 32 employed when other types of ions are to be accelerated will be such as are not dependent upon diffusion through a diffusion barrier.

Exemplary of arrangements suitable for producing neutrons is the acceleration of deuterons where the target 38 includes nuclei of tritium, or conversely, accelerating tritons to strike the target 38, where the target includes nuclei of deuterium. Either of these arrangements where the ions are accelerated through a potential of at least about 20 kilovolts will result in the production of 14 mev. neutrons. 2.5 mev. neutrons can be produced by similarly accelerating deuterons to strike the target 38 where the latter contains nuclei of deuterium. Where the target 38 is to include nuclei of tritium or deuterium, the target 38 can conveniently take the form of a plate of tungsten having a layer of zirconium, titanium, or the like on the side thereof adjacent the accelerator 36, with the zirconium having tritium or deuterium adsorbed therein, as the case may be.

Where it is desired that the penetrating radiation be gamma rays, many combinations of types of bombarding ions and types of nuclei to be included in the target will occur to those skilled in the art. For example, the bombarding ions can be protons and the target include nuclei such as ${}^7_3\text{Li}$, ${}^{19}_9\text{F}$, ${}^{12}_6\text{C}$, or ${}^{13}_6\text{C}$. Higher accelerating potentials are required to cause gamma-ray producing reactions of these combinations than the previously mentioned neutron producing reactions. Accordingly, an appropriate selection of high voltage source for the accelerator must be made in view of the fact that for maximum yield protons must be accelerated by a potential on the order of about 450 kilovolts to react with ${}^7_3\text{Li}$ to produce 17 mev. gamma rays; 350 kilovolts to react with ${}^{19}_9\text{F}$ to produce 6 mev. gamma rays; 450 kilovolts to react with ${}^{12}_6\text{C}$ to produce 2 mev. gamma rays; and 560 kilovolts to react with ${}^{13}_6\text{C}$ to produce 8 mev. gamma rays; also, the target can include nuclei of ${}^9_4\text{Be}$ to produce gamma rays of various energies up to about 7 mev. where an accelerating potential of about 1 megavolt or better is available. Lesser accelerating potentials can be used in such combinations with reduced gamma-ray yield.

The ionic pump 40 is of the type that vaporizes a getter material, such as zirconium or titanium, so that the getter material condensed on adjacent surfaces will absorb ambient gases and thereby maintain a pressure within the accelerator 36 on the order of 10^{-5} to 10^{-6} mm. Hg. The ionic type of pump 40 is especially preferred for the reason that I do not know of any other type pump having a comparable efficiency and the requisite degree of re-

liability and ruggedness in operation that is sufficiently small to meet the stringent space limitations imposed in borehole logging equipment. The container 24 is provided with openings 62 and 64, so that the pump 40 can directly evacuate the interior of the accelerator 36, and also directly evacuate the space intervening between the cathode 48 and the probe electrode 56 though an additional pump, not shown, can be employed for the latter purpose.

Attention is now directed to FIGURE 3 wherein the electrical circuitry associated with the previously described elements is schematically illustrated. Indicated at 66 is a high voltage supply having a sufficiently high voltage output for accelerating ions to the necessary energy to undergo the nuclear reaction productive of the penetrating radiation which can conveniently be of the Van de Graaff or Cockcroft-Walton type. The negative terminal 68 of the supply 66 is grounded as at 70 and also connected by a lead 72 to the accelerating electrode 60. The positive terminal 74 of the supply 66 is connected by a lead 76 to the accelerating electrode 58, and is also connected by a lead 78 to the negative terminal 80 of a further high voltage supply 82 for energizing the ion source. The positive terminal 84 of the supply 82 is connected by a lead 86 to the anode 50. The probe electrode 56 and the cathode 48 are adjustably connected to intermediate voltage taps of the supply 82 by leads 88 and 90, respectively. The cathode 48 is connected to the cathode 46 by a lead 92.

The target 38 is adjustably tapped to the supply 66 through a current responsive device 94 by leads 96 and 98. The target 38 is so tapped to the supply 66 so as to have a voltage sufficiently more positive than the accelerating electrode 60 so as to prevent electrons formed at the target 38 from reaching the electrode 60.

The current responsive device 94 is responsive to the current flowing through the lead 96 for controlling the rate at which electrical energy is supplied to the heating element 44 of the palladium thimble 42 through leads 100 and 102. The function is such that whenever the current through the lead 96 exceeds a predetermined value, the rate at which energy is supplied to the heating element 44 is progressively decreased, and, conversely, whenever the current in the lead 96 falls below said predetermined value, the rate at which energy is supplied to the heater element 44 is progressively increased. Since higher temperatures of the palladium thimble 42 are accompanied by an increased flow of gas therethrough so as to result in a greater target current flowing in the lead 96, it will be apparent that the control of the energy supplied to the heater element 44 is such as to stabilize the current flowing in the lead 96 at said predetermined value. Such stabilization of the target current contributes substantially to stabilization of the output of penetrating radiation by the target 38.

The current responsive device 94 can be a conventional servo system adapted to function as above specified wherein the output of the sensing element thereof is responsive to variations of the electrical current in lead 96 to control by means of an electric motor the supply of electrical energy to the heating element 44 of the thimble 42. For example, though many other forms of servo systems or equivalents thereof will readily occur to those trained in this field, the current responsive device can be such as that illustrated in FIGURE 2 of U.S. Patent No. 2,735,943 issued February 21, 1956, to Wright et al., wherein the motor 72 thereof is arranged to drive a variable rheostat controlling the supply of electrical energy to the heating element 44.

As will be appreciated by those skilled in the art, the electrical leads 100 and 102 can be applied to control equivalent forms of electrically controlled valve means that do not involve diffusion, as has been previously indicated.

A source of electrical energy 104 is provided for energizing the ionic pump, the same being connected thereto by leads 106 and 108 with the lead 108 being grounded, as shown. The operation of the source of penetrating radiation shown in FIGURES 2 and 3 will be readily understood. It will be assumed for purposes of description that deuterons will be accelerated to strike the target 38, the latter including nuclei of tritium, so that 14 mev. neutrons are produced. It will also be assumed that the pressure within the accelerator 36 is on the order of 10^{-5} to 10^{-6} mm. Hg, and that the pressure within the ion source 34 is on the order of 10^{-3} to 10^{-4} mm. Hg. The reservoir 30 is filled with deuterium gas at a pressure atmospheric or greater.

Deuterium ions are formed within the ion source 34 and a proportion of such ions pass from the ion source 34 through the restricted exist 54 into the accelerator 36 after which they are accelerated to an energy in excess of about 20 kilovolts and strike the target 38 so as to react with nuclei of tritium included in the target 38. It will be understood that neglecting certain factors such as varying target conditions, the radiation output of the target 38 varies generally in a manner proportional to the magnitude of the ion current striking the target 38. Stabilization of the magnitude of the target current is achieved, as previously described, through the control of the electrical energy supplied the heater element 44 in response to the magnitude of the current flowing in the lead 96.

Means can be provided for detecting and recording any particular kind or specific energy portion of radiation entering the borehole 10 from the earth formations 110 adjacent the housing 12 as a consequence, however indirect, of the earth formations 110 being subjected to penetrating radiation from the target 38. Many types of detecting and recording means for such purposes are known in the borehole logging art, and the type to be employed with the previously described apparatus is substantially merely a manner of selection with respect to the purpose at hand. The particular form of detecting and recording means illustrated comprises radiation detector 112 of the type that is a combination of a scintillation phosphor sensitive to gamma rays and a photomultiplier tube, the output of the detector 112 being fed first to an amplifier 114 and thence to a pulse-height analyzer 116. The pulses passed by the pulse-height analyzer 116 pass out of the borehole 10 to the earth's surface by way of the electrical conduit means 16 included within the cable 14 and are fed by a conventional pickup means 118 connected to the reel 20 to a conventional recording means 120 that records the pulse heights versus the depth of the housing 12 within the borehole 10 by means that includes an operative connection to the pulley 18 indicated by dashed lines 122.

Also, as a check upon the constancy of the ion current passing through the lead 96, the electrical potential difference between the leads 100 and 102 is recorded versus the depth of the housing 12 within the borehole 10 by means that includes leads 122 and 124 connected respectively to the leads 100 and 102, the electrical conducting means 16, a pickup 124, and a conventional recorder 126 also operatively connected to the pulley 18, as indicated by dashed line 128.

Shielding means 130 substantially opaque to the penetrating radiation produced by the target 38 is interposed between the target 38 and the radiation detector 112. When the penetrating radiation is gamma rays, the shielding means 130 can conveniently be constituted of lead; and when the penetrating radiation is neutrons, the shielding means 130 can be constituted of a mass of paraffin having a layer of cadmium on the side thereof remote from the target 38. Where the penetrating radiation consists of both gamma rays and neutrons, the shielding means 130 can be comprised of a layer of cadmium interposed between masses of paraffin and lead, with the

paraffin and the lead being disposed respectively adjacent the target 38 and the radiation detector 112.

The alternative embodiment of the invention shown in FIGURE 4 that can be used in lieu of the apparatus shown in FIGURE 3 comprises a high voltage supply 132 which can be the same type as the previously described supply 66. The negative terminal 134 of the supply 132 is grounded as at 136, and is connected by a lead 138 to the electrode 60. The electrode 58 is adjustably tapped to the positive side of the supply 132 by a lead 140, and the positive terminal 142 of the supply 132 is connected by a lead 144 to the negative terminal 146 of a high voltage supply 148 that can be of the same type as the previously described supply 82. The probe electrode 56 and the cathode 48 are adjustably tapped to the positive side of the supply 148 by leads 150 and 152, respectively. The cathodes 46 and 48 are connected by a lead 154.

The target 38 is adjustably tapped to the supply 132 by leads 156 and 158 through a current responsive device 160. The voltage of the target 38 is adjusted to be sufficiently more positive than that of the electrode 60 so that electrons produced at the target 38 do not pass to the electrode 60.

The function of the current responsive device 160 is to control the potential difference between a pair of terminals 162 and 164 in response to the magnitude of the ion or target current flowing through the lead 156. The arrangement is such that as the current in the lead 156 exceeds a predetermined value, the terminal 164 is caused to become increasingly more positive with respect to the terminal 162, and conversely, when the current in the lead 156 falls below said predetermined value, the potential of the terminal 162 is caused to become increasingly more positive with respect to the terminal 164. The terminals 162 and 164 are connected respectively to the anode 50 and the positive terminal 166 of the supply 148 by leads 168 and 170. Thus, as the ion current in the lead 156 increases above said predetermined value, the potential difference between the anode 50 and the cathodes 46 and 48 is decreased, and, conversely, when the ion current in the lead 156 falls below said predetermined value, the potential difference between the anode 50 and the cathodes 46 and 48 is increased.

Inasmuch as an increase in the potential difference applied to the electrodes of the ion source 34 increases the rate at which ions are supplied thereby to the accelerator 36, it will be apparent to those skilled in the art that the above described means for controlling the potential difference supplied to the ion source 34 tends to stabilize the ion or target current constituted of ions bombarding the target 38 flowing in the lead 156.

The current responsive device 160 can be a conventional servo system adapted to function as above specified wherein the output of the sensing element thereof is responsive to variations of the electrical current in lead 156 to control by means of an electric motor the electrical potential difference between terminals 162 and 164. For example, though many other forms of servo systems or equivalents thereof will readily occur to those trained in this field, the current responsive device 160 can be similar to that disclosed in the previously mentioned patent wherein the motor 72 thereof is applied to control a variable potentiometer. It will be understood that the device 160 includes a conventional provision for isolating the high potentials of the leads 168 and 170 from ground potential such as an isolation transformer, as will be appreciated by those skilled in the art.

Leads 172 and 174 are connected to the leads 168 and 170, respectively, and can be used in connection with the recorder 126 in lieu of the previously described leads 122 and 124, it being understood that conventional means not shown are employed to isolate the high potentials of the leads 172 and 174.

The ionic pump 40 is connected to a source of electrical energy 176 by leads 178 and 180, the latter lead being

grounded with the terminal 134 of the supply 132, as shown.

The electrical heater element 44 is energized from a source of electrical energy 182 by leads 184 and 186, the latter lead 186 preferably being connected to the cathode 46 by a lead 188. The source of electrical energy 182 is selected so that the heater element 44 is energized to such an extent that gas will diffuse through the palladium thimble 42 at such a rate as to substantially equal the rate at which ions are supplied to the accelerator 36 from the ion source 34, thereby maintaining the pressure within the ion source 34 reasonably constant. Alternatively, the rate of supply of electrical energy to the heater element 44 can be made dependent upon the rate of current flow in the lead 168 according to the principles disclosed in my previously mentioned copending application entitled "Logging Apparatus."

It will be understood of course that the elements 132, 148, 160, 176 and 182 can be placed within the housing 12 in the same location as the elements 66, 82, 94 and 104 of the previously described embodiment of the invention. With respect to both embodiments of the invention, the sources 104 and 176 can be disposed in the housing 12 above the casing 22, if deemed necessary or expedient in view of such elements being at ground potential.

The operation of the modified embodiment of my invention shown in FIGURE 4 will be readily appreciated. During operation ions are formed in the ion source 34 and supplied to the accelerator 36 where they are accelerated to strike the target 38 in a diffuse pattern. The ion or target current constituted of ions striking the target 38 passes through the lead 156 and the current responsive device 160. The current responsive device 160 functions to control the electrical potential applied between the anode 50 and the cathodes 46 and 48, as previously explained so that such potential is increased whenever the ion current falls below a predetermined value, and conversely, whenever the ion current exceeds a predetermined value whereby the ion current is maintained substantially constant at said predetermined value. Since the output of penetrating radiation from the target 38 is to a large extent proportional to the magnitude of the ion current bombarding the target, the output of penetrating radiation is maintained substantially constant upon the target current being maintained substantially constant.

As explained in connection with the previously described embodiment of the invention, the palladium thimble 42 and the electrical heating element 44 can be replaced by equivalent electrically controllable valve means of conventional character connected to the leads 184 and 186.

Means, not shown of conventional character are provided in connection with either embodiment of the invention for supplying electrical energy to the elements in the housing 12 through the cable 14.

The preferred embodiments of the invention hereinbefore described are susceptible to numerous variations without departing from the scope of the invention. Exemplary of such modifications is the fact that the electrodes of both the ion source 34 and the accelerator 36 can be preconditioned as described in my copending application entitled "Logging Apparatus" so as to assist in maintaining a pressure differential between the accelerator 36 and the ion source 34 in favor of the latter. Also, the accelerator 36 can be modified to employ other well known principles of linear particle acceleration, such as exemplified by micro-wave pulsing techniques. Furthermore, where it is desired to pulse the output of penetrating radiation from the target 38 as for such a purpose as disclosed in U.S. patent application Serial No. 430,009 entitled "Radiological Surveying Method and Apparatus" filed May 17, 1954, by Charles W. Tittle, well known conventional means can be conveniently employed for this purpose such as means for interrupting the current in

leads 86 and 168, it being understood that the periodic interruptions of current flow do not significantly disturb the functions of the current responsive devices 94 and 160.

The preceding detailed description of the invention has been given for the purpose of conveying a complete and full understanding of the invention, and the elaborate detail of the description is not to be taken as implying narrowness of scope of the invention. Reference should be made to the appended claims in order to ascertain the scope of the invention.

I claim:

1. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, and means for promoting stability of the output of the produced radiation comprising electrically controllable means regulating the rate at which ions are supplied to the accelerator from the ion source, current-responsive control means having input and output terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target, and means connecting said output terminals of said control means to said controllable regulating means, whereby said regulating means is controlled with respect to ion current bombarding said target.

2. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, said ion source including an anode and a cathode and controllable means for establishing an electrical potential difference between said anode and said cathode, and means for promoting stability of the output of the produced radiation comprising current-responsive control means having input and output terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target, and means connecting said output terminals of said control means to said potential-difference-establishing means, whereby the potential difference between said anode and said cathode of said ion source is controlled with respect to ion current bombarding said target.

3. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, said ion source including an anode and a cathode and controllable means for establishing an electrical potential difference between said anode and said cathode, and means for promoting stability of the output of the produced radiation comprising current-responsive control means having input and output terminals and adapted to vary the potential difference across its output terminals as an inverse function of the current flowing between its input terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target and means connecting said output terminals of said control means to said potential-difference-establishing means, whereby the potential difference between said anode and said cathode of said ion source is controlled as an inverse function of the ion current bombarding said target.

4. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, controllable means for

introducing a material to be ionized into the ion source at a controlled rate, and means for promoting stability of the output of the produced radiation comprising electrical means regulating the rate at which ions are supplied to the accelerator from the ion source in response to the magnitude of the ion current constituted of ions bombarding the target, said electrical means comprising current-responsive control means having input and output terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target, and means connecting said output terminals of said control means to said controllable material-introducing means, whereby the rate of introduction of material to said ion source is controlled with respect to ion current bombarding said target.

5. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, controllable means for introducing a material to be ionized into the ion source at a controlled rate, and means for promoting stability of the output of the produced radiation comprising electrical means regulating the rate at which ions are supplied to the accelerator from the ion source to the accelerator in response to the magnitude of the ion current constituted of ions bombarding the target, said electrical means comprising current-responsive control means having input and output terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target, and means connecting said output terminals of said control means to said controllable material-introducing means, said control means

being adapted to activate said material-introducing means as an inverse function of the input current to said control means.

6. A stabilized source of penetrating radiation comprising an ion accelerator, a target positioned to be bombarded by ions accelerated by the accelerator, said target including atomic nuclei reactive with bombarding ions to produce the penetrating radiation, an ion source for supplying ions to the accelerator, a reservoir of material to be ionized, a diffusion barrier separating said reservoir from said ion source, electrical heating means adapted to heat said diffusion barrier, current-responsive control means having input and output terminals, means connecting said target to said input terminals of said control means thereby rendering said control means responsive to ion current bombarding said target, and means connecting said output terminals of said control means to said electrical heating means, said control means being adapted to increase the electrical energy supplied to said electrical heating means in response to a decrease of current input to said control means.

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